

OVERVIEW OF
FEDERAL WIND ENERGY PROGRAM

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This discussion will provide a brief overview of what the Federal Wind Program is today, what the objectives are, and what strategies are being followed. Some of the changes in the program structure and some of the additions to the program will also be included. There will be mention of upcoming organizational changes, and some budget items will be covered, with particular mention of some recent significant events regarding new approvals. Lastly, there will be a question and answer session after the formal remarks.

First of all, the overall objective of the Federal Wind Program is to get the Government out of the wind energy business. It is our desire to develop machines that are reliable and truly cost competitive. In this way, industry will be moved to the point where it can produce wind machines and sell them to utilities and to private individuals so that significant quantities of electrical energy can be captured from the wind.

The general thrust of the program is to start with mission studies and application studies. As you know, we have come a long way from some of the early machines to the machines that are now in use. It is hoped, through the Wind Energy Program, to go a long way beyond that.

The strategy used to achieve the objectives is based on the elements shown in figure 1. The first activity, Application Studies, will be combined with Legal, Social and Environmental Studies and some long range planning activities to comprise a new program element that is called Research and Analysis. This new program structure will be seen more frequently in the publications such as program summaries that emanate from Washington.

Wind Characteristics will continue to stand alone as a very important and significant part of wind energy research. Technology Development also will continue as a separate element, since it is an important area that feeds into all of the Experimental Systems Development programs, which is the next item. This category includes the small machines, the intermediate sizes, and the large machines for the various applications.

There will eventually be another element added to the bottom line to show Applications and Demonstrations. This will be a new line item referring to future marketing activities that we feel will have to be done. In fact, budgets are being planned for this new element which will be added to the program. The first budget reflecting this activity will be in fiscal year 1981.

The principal items covered in each of the major program elements are listed in figure 2. Some of the activities involved in these items will now be discussed.

MISSION AND APPLICATION STUDIES

There have been a number of studies that look specifically at applications for wind turbines (fig. 2(a)). For example, the New England Gas and Electric System was chosen as the subject for a study of the economics and some technical issues of implementing wind turbines in an existing utility grid. The NEGEA service region is shown on the map of figure 3 with some of the wind characteristics for that area. Other studies have been done for such areas as Hawaii and Michigan. In fact, we also looked at more specific applications. For example, a study was done by Aerospace Corporation on the application of wind power to the California aqueduct system. There are studies under management of the U.S. Department of Agriculture for applying wind power in farm applications. Figure 4 shows one of the machines that is running today on a farm.

There are several studies, started recently, that fall into this general area of missions and applications. Two of them, in particular, involve working with the Tennessee Valley Authority to examine the implementation of a significant penetration of wind turbines into that general area. Specifically, the study is looked at the operational problems associated with interconnecting large wind turbines on the TVA grid with their generation mix.

Another study just recently started is examining the issue (economic factors in particular) of applying wind energy conversion systems in rural electric co-op activities. More of such studies will be initiated as the program develops.

Testing of experimental wind turbines remains a major part of the program. You may recall the 17 candidate sites that were picked from a group of about 55 proposals several years ago. A number of these sites now actually have machines operating on them. The map of figure 5 shows the current 17 sites. According to our current planning, there may be another round of site selections this summer for future machines.

LEGAL, SOCIAL AND ENVIRONMENTAL ISSUES

Legal, social and environmental issues (fig. 2(b)) are a very significant part of the Wind Program. Legal concerns in a number of areas have been encountered; land use is one. There has been concern about where wind turbines might be sited, e.g., the aesthetics of wind turbines and the public reaction to their visual impact. For example, figure 6 shows a picture of a MOD-2 mounted on top of a hill. Actually, there are three machines along a ridge spaced typically about a quarter of a mile apart. The initial reaction is that there probably isn't any serious visual impact involved, but it is an issue that must be considered in siting machines.

Public safety is a social question involving the zoning of the area around a wind turbine. When a wind turbine is installed on a site, there is an area underneath the machine called a footprint, which must be owned outright. Such a piece of land might be of the order of an acre in size. However, there is an additional area around the base of the machine that may

be used for agricultural or other purposes, but not for dwellings. This area might be called a safety zone. It is probably analogous to the area underneath or in the vicinity of power lines. It is an item of concern at this time because land use problems are a part of life today, especially the approval of environmental impact statements.

Machines are often located in isolated areas. Figure 7 shows the MOD-0A at Culebra, Puerto Rico, which is a pretty isolated area. In such cases, there isn't much of a land use problem.

Another potential environmental impact from wind turbine is electro-magnetic signal interference. An example is the TV interference problem. This is actually a reflection situation where the video portion of television signals may be reflected by rotating blades (fig. 8). This can cause an interference for people living in the immediate proximity of the wind turbine. We think we have solutions to this kind of problem.

WIND CHARACTERISTICS

One of the major aspects of the Wind Characteristics program (fig. 2(c)) is the determination of the wind resources in the United States. In the map of figure 9, the areas that have the highest wind are shaded, followed by lighter shading, and the more benign areas are unshaded. This is a very broad estimate of the resources that are available. Consequently, it is necessary to establish in more detail what resources are available in specific areas. As a prototype for that kind of a study, we examined the Northwestern region of the United States and acquired as much wind data as possible. The pins in the map of figure 10 represent sites where some kind of wind data was acquired. Sources are the traditional sites such as airports, NOAA stations (where very good detailed data are obtained), and other less obvious sites such as forest service fire towers. Many different kinds of information were compiled in an effort to determine the wind resources in more detail in that region. The study of the Northwestern region is about to be published. This work will serve as the basis for additional studies in the rest of the United States. In fact, requests for proposals to do other regions of the U.S. were issued, and the replies are in.

The wind resources studies and their attendant mathematical modelling are a very important step leading to the identification of a potential site for a wind turbine. An anemometer tower such as the one shown in figure 11 can then be placed at the potential site to evaluate in detail what the resources are. It is important to recognize that anemometer towers are very expensive, and locations must be carefully selected. The wind area studies provide a necessary tool to predict where the best resources are.

In regard to wind resources, it should be noted that siting handbooks will be made available. One for small wind machines has already been published. Another one is in the mill for large machines. Hopefully, these will help utilities and private individuals to properly site their machines.

Wind forecasting is the last area that should be mentioned. There is a lot of information available. It is basically a matter of organizing the information and translating it into a language that wind system users can understand.

TECHNOLOGY DEVELOPMENT

Activities in the Technology Development area (fig. 2(d)) can be illustrated by the familiar MOD-0 machine at the Plum Brook station. Figure 12 shows a photograph of the present installation. A lot of things have changed on that machine. As part of the technology development program, NASA has been doing extensive modifications of the MOD-0 machine. The blades in the figure are not the original blades. The one shown is a forerunner of the tip control teeter arrangement that is being tested on the machine now. Hopefully, it will be seen during the inspection tour.

The whole thrust of this program is, through component development and analytical studies, to learn the basic phenomena involved, so that the wind can be harnessed in a cost-effective way.

It should be mentioned, that since this is a workshop, one of the things to be determined is whether there are some things that we are not doing. In recalling the Dynamics Workshop that was held here about a year or so ago, there was considerable discussion at that meeting as to whether the MOD-0 machine should be run in a free yaw mode; that is, instead of using the motors to keep the machine pointed into the wind, to let it run free. NASA was almost challenged to try that mode of operation. As a result of the workshop, it was tried, and after a lot of analytical study, it was determined and verified on the MOD-0 that free yaw worked and that the blade wouldn't wrap around the tower.

A lot of other things were also tried, such as an upwind rotor and a downwind rotor and much significant data will be reported today. There are many things that are being done in technology development, and it is hoped that this meeting will reveal other things that should be done.

Components are another major element in technology development. Figure 13 shows a 150 foot blade that was built to evaluate new transverse filament fiberglass-reinforced plastic materials and manufacturing techniques for large blades. This type of blade, which had never been built before and which some people called the world's largest fiberglass fishing pole, was successfully fabricated and tested.

Figure 14 shows another blade that is currently flying on the MOD-0 machine. This blade, which was built here at NASA, uses a potentially very inexpensive construction technique. The spar of this blade is built from what might be called a telephone pole or utility pole. The airfoil shape is built up from wood ribs covered with razorback cloth. The idea here was to not only obtain a low-cost construction technique, but also to construct a blade that could easily be changed to a tip control configuration. More will be heard about this today.

The technology program is not limited to horizontal axis machines. Much will be presented in this conference about vertical axis machines. Figure 15 shows the Darrieus Machine at Sandia Labs, which is definitely one of the promising areas. There are indications now that the Darrieus vertical axis design, in general, may be able to compete directly with the horizontal axis machine. Thus, this area of the program is currently receiving more attention.

INNOVATIVE CONCEPTS

Innovative concepts (fig. 2(e)) are a relatively small part of the program. The thrust of the innovative program is to be sure that we don't miss any ideas. It may be analogous to the days of the piston engine for aircraft applications. We don't want to overlook something big like the jet engine.

Many studies are being conducted on augmentation devices such as the Coands diffuser shown in figure 16. Other types of augmentation, some a little more noval looking, are being examined. Figure 17 shows another augmentation device. If the diffuser of figure 16 had the shell cut away and just little pieces were left at the tips of the rotor blades, the configuration of figure 17 would be obtained. This study was done by AeroVironment on what they call a dynamic inducer. The designs mentioned here are not the entire effort. The intent is to illustrate the kinds of things that are included in the innovative program.

SYSTEM DEVELOPMENT

The end product of the program of course is systems development. Let's start with the small machines (fig. 2(f)), where small machines are defined as those with less than a 100 kW power output. There is a test center now in operation at the Rocky Flats facility of the Department of Energy in Colorado. Figure 18 shows a number of machines that are currently being tested at the Rocky Flats facility. Although they are now shown in the figure, there are a number of small vertical axis machines under development. Most of those shown are very small machines, but there are now development programs leading to larger machines. Figure 19 is another example of one of the commercial machines that is currently being tested at Rocky Flats. This evaluation is being done in an effort to help manufacturers to understand the capabilities of their machines and also to determine the performance of various configurations.

Figure 20 illustrates the three approaches that are being taken to develop highly reliable 1- to 2-kW size machines. There are two propeller type machines and a vertical axis machine. Eight-kilowatt size machines are shown in figure 21. There are four parallel developments in this category; again, a mixture of vertical axis and horizontal axis machines. In the 40-kilowatt size, as shown in figure 22, there are two parallel developments with one vertical and one horizontal axis machine. There are some advanced development programs about to be started in other sizes, specifically for 15 and 4 kW.

Let's now consider the machines in the intermediate and large size range. Intermediate sizes machines are arbitrarily defined as those with capacities larger than a 100 kW and yet smaller than 500 kW. Figure 2(g) lists the intermediate and large machines.

A machine that falls into the lower category is the MOD-0A. The installation in Culebra, Puerto Rico, was shown in figure 7, and the installation in Clayton, New Mexico, is shown in figure 23. The MOD-0A machine will be discussed extensively during the conference. The 2-mW MOD-1 machine, which is being installed in North Carolina, is shown in figure 24. For the largest, figure 25 shows an artist's concept of the $2\frac{1}{2}$ mW MOD-2. This machine is now in the detailed design phase, and hopefully the machine will be running in the fall of 1980.

As far as advanced systems are concerned, we have recently received approval to initiate two new advanced systems. One is in the intermediate size range and the other is in the large multi-megawatt size range. This resulted after much reevaluation of the Wind Energy Program with regard to timing, the applications, and the markets for these machines. An RFP should be issued for the first of those machines later this fiscal year. The requirements of those machines, in particular the large one, merit some discussion.

A chart showing the cost trends of wind turbines is shown in figure 26. Three categories of costs are indicated in the upper righthand corner. The clear band represents preproduction costs. That refers to units purchased in groups of ones and twos, as opposed to the second slashed band below, which illustrates costs associated with limited production. This category represents a production of up to 25 machines or groups of 25 which still constitutes limited production. The dotted band represents what is considered the mature product projection (units of 100's).

On the left axis of figure 26 (note that the axis is broken with a changed scale), the first generation machines are the MOD-0's, MOD-0A's and the MOD-1. The costs for these very early prototypes are 20 to 30 cents a kW hour. Even if they were produced in large quantities and were located in very high wind sites, (like 16 mph), the cost would be reduced to only around 6 or 7 cents a kilowatt hour.

The second generation machines look a little different. The MOD-2, hopefully, will be able to attain a useful market for reasonable site wind speeds (down to 14 mi an hr) in the early 80's, to the point where it actually would compete with other fossil fuel-generating sources in areas where fuel costs are high. However, to really achieve broad and significant market, it is necessary that advanced systems be built that have a significant improvement over that which can be achieved with MOD-2.

Our goals are to produce machines at a cost of energy from 2 to 3 cents a kW hour. Our present program in the large machines is to have one more round of advanced system developments. By that is meant that there will be, budget permitting, parallel contracts to develop what are envisioned as the last generation of advanced machines. Invariably, there will be product improvement

programs and similar activities, but it is felt that the goal can be achieved in this round. The last set of bars to the right in figure 26 may be unnecessary.

For the intermediate sizes, the cost figures are somewhat less tight. The exact numbers are still being determined. We hope to achieve a useful market range in the intermediate size machines, but we still plan to have an additional cycle of advanced machines beyond the one that will be coming out this year.

How these goals and plans are going to be accomplished is really the topic of this meeting. Elements of the cost reduction activities are outlined in figure 27. We have asked NASA to supply a form of shopping list of the program activities that they feel will bring us from the current $3\frac{1}{2}$ cents a kW hour down to $2\frac{1}{2}$ cents a kW hour. It is strongly felt that weight and cost budgets can, in fact, be controlled to the point where a machine can be produced in that range. However, much technology work is needed to reach that cost level. Consequently, these programs will be structured to allow a significant amount of time at the start of the development programs to examine alternative ideas to achieve machine configurations that can attain those exacting goals.

The present workshop should be a fertile ground for ideas to suggest test programs that can investigate some of these areas. Hopefully, it will be an opportunity for people to interchange ideas and promote the task of developing required advanced systems.

PROGRAM RESOURCES

The budget for the Wind Program has seen considerable growth. In fiscal years 1973 and 1974 combined, it was about \$2 million. Last fiscal year, it grew to about \$36 million. The budget for this current year is about \$61 million. Figure 28 compares the 1978 and 1979 budgets. Although the value for next year is not yet known, it appears to be in excess of \$67 million. Numbers as high as \$100 million are heard. The Congressional hearings are going on currently, so the fiscal year 1980 budget is not known. However, a significant growth in that area is foreseen.

The other significant resources that we have to discuss is people. In addition to the expected two new slots in Washington, a new DOE Area Office will be set up to handle those aspects of the program that relate to small machine development, wind characteristics, and vertical axis machines. That office in Albuquerque, which will be set up by George Tennyson, is expected to be operational in July of this year.

SUMMARY

The Wind Energy Program has had significant growths, technically, organizationally, and budgetwise. However, a very significant challenge remains. The cost goals that have been established for advanced systems are tough. Very

aggressive technical development programs will have to be mounted to achieve them. As can be seen from the organization of this conference, a number of unknowns have been recognized that will require addressing. However, it is the unknown unknowns that are worrisome. Hopefully, this conference will provide an opportunity for people to surface potential problem areas that should be investigated.

That basically is the challenge. Our strengths are recognized and acknowledged, but let's try to identify our weaknesses. Hopefully, in so doing, our goals will be reached.

REFERENCE

Wind Energy Systems Program Summary. U.S. Department of Energy, Office of Solar, Geothermal, Electric and Storage Systems. DOE/ET-00093, December 1978.

DISCUSSION

- Q. Is work continuing on offshore site selection?
- A. With regard to site selection, proposals are invited from any site area. There have been no proposals for offshore sites. There is a study conducted by Westinghouse that showed very difficult technical problems and high costs with placing machines offshore. This study is just about complete, and it should be published in the near future. There is no question that there are good resources offshore, but the technical problems and costs are of major consideration.
- Q. You have presented a very good program which concentrates on Government efforts. Since the stated objective is to put the Government out of business, what efforts are being made to relate to the private activities that are going on in wind turbine development, such as Schackle and others?
- A. The Federal Wind Program was summarized, since that was my assignment. However, our feeling about the private effort is that if there is anything we can do to help and encourage that effort, we will respond. It is excellent that private ventures are starting. It is a sign that a healthy market may be developing.

Federally sponsored R & D activities are open to anyone. We issue a RFP for advanced systems, and anyone can bid. Private companies that chose not to bid on federal contracts, for reasons which are understandable, can shift from the private sector into the government R & D at any time. Also, the reports that are published and the technology that is developed under government funding are available to private entrepreneurs. We encourage the use of such information, and when requests are received, we generally will supply bibliographies and any knowledge that is available.

OVERALL APPROACH

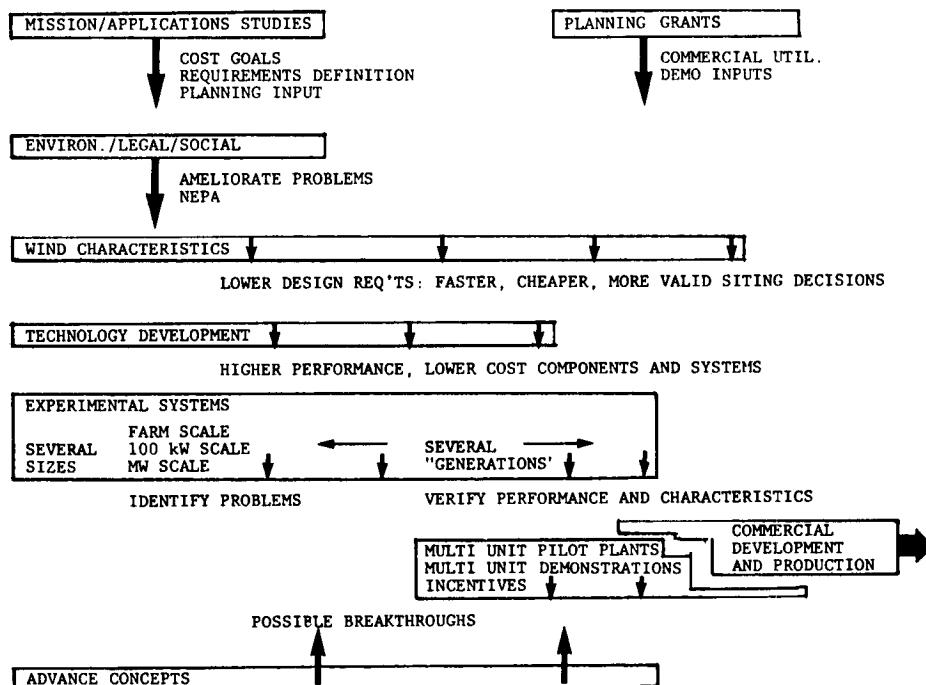


Figure 1

MAJOR PROGRAM ELEMENTS

- (a) MISSION AND APPLICATIONS ANALYSIS
 - * Mission and Market Studies
 - * Utility and Specific Applications
 - * Candidate Sites
- (b) LEGAL SOCIAL AND ENVIRONMENTAL ISSUES
 - * Machine Aesthetics
 - * Siting and Land Use
 - * Wind Rights
 - * Energy Cost and Rates
 - * Codes and Standards
 - * Environmental Impacts
- (c) WIND CHARACTERISTICS
 - * Resource Assessments
 - * Area Survey Techniques
 - * Siting Handbooks
 - * Forecasting and Operation
- (d) TECHNOLOGY DEVELOPMENT
 - * Experimental Machine
 - * Component Development
 - * Analytical Model: Aerodynamic; Structural Dynamic; Power Grid Stability
- (e) INNOVATIVE CONCEPTS
 - * Augmentation
 - * Vertical Axis
 - * Unique Approaches
- (f) SMALL SYSTEMS DEVELOPMENT
 - * Test Center
 - * Commercial Machine Tests
 - * New Systems Development
- (g) LARGE SYSTEMS DEVELOPMENT
 - * MOD OA 200 kW machines
 - * MOD 1 2 mW machine
 - * MOD 2 2.5 mW machine

Figure 2

**WIND SPEED CONTOURS IN THE
NEGEA CAPE COD SERVICE REGION**
(reference height = 10 meters)

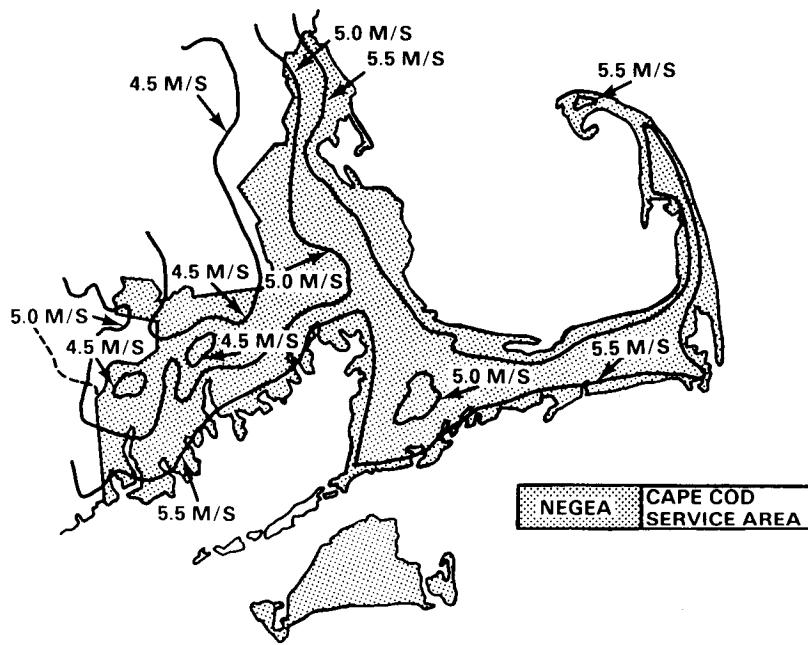


Figure 3

FARM WINDMILL (U.S.D.A.)



Figure 4

WTG CANDIDATE AND INSTALLATION SITES

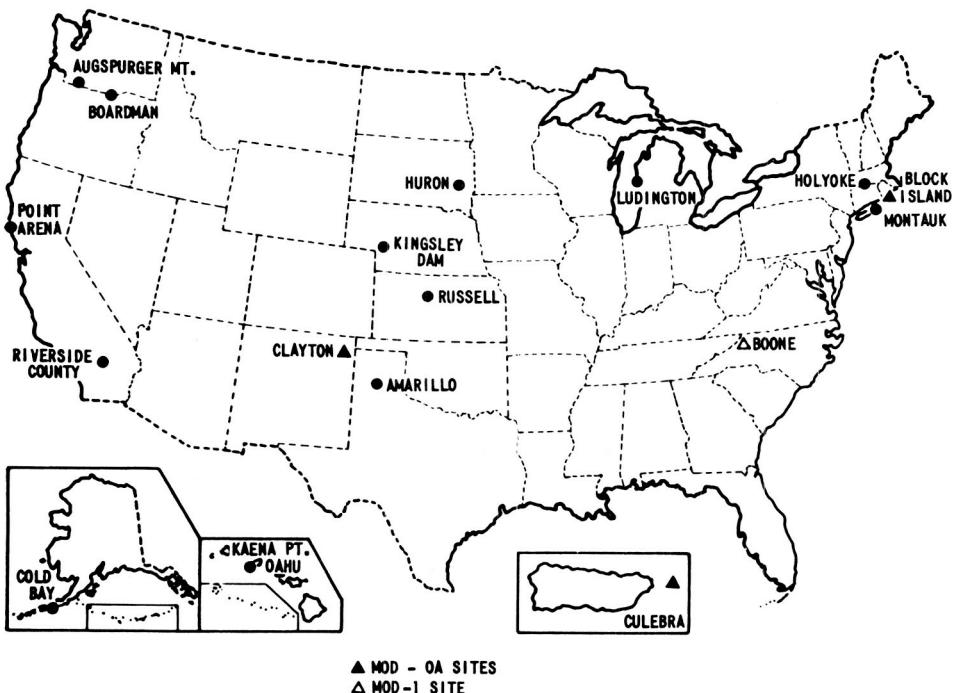


Figure 5

ARTIST CONCEPTION OF MOD-2 TURBINES ON A RIDGE

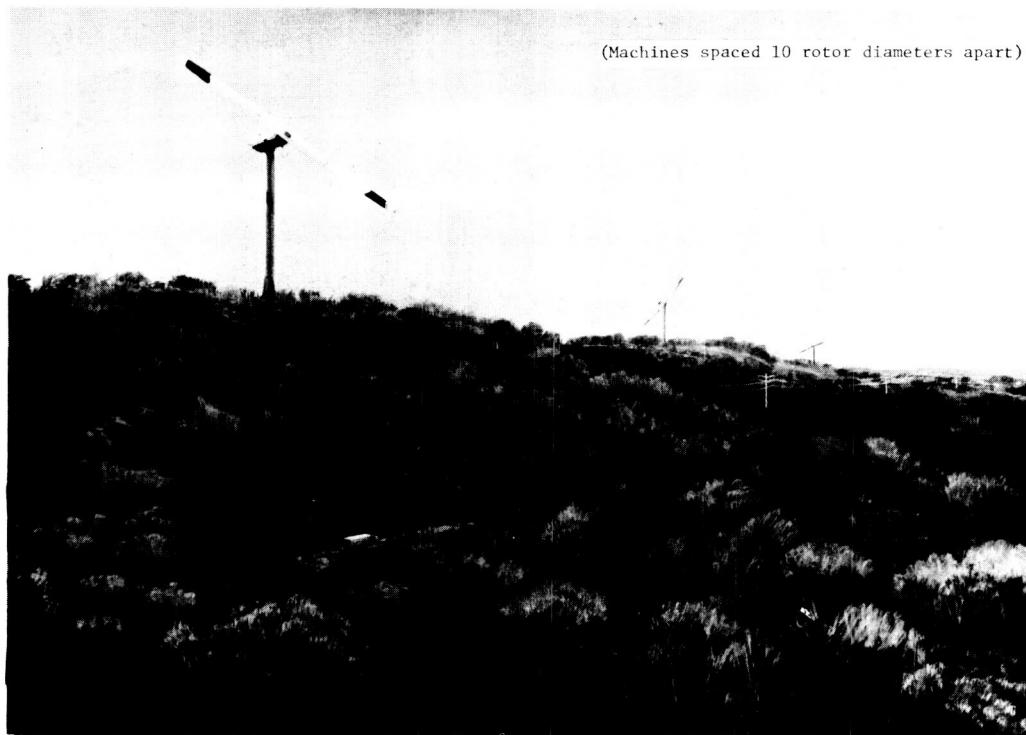


Figure 6

MOD-0A AT CULEBRA, PUERTO RICO



Figure 7

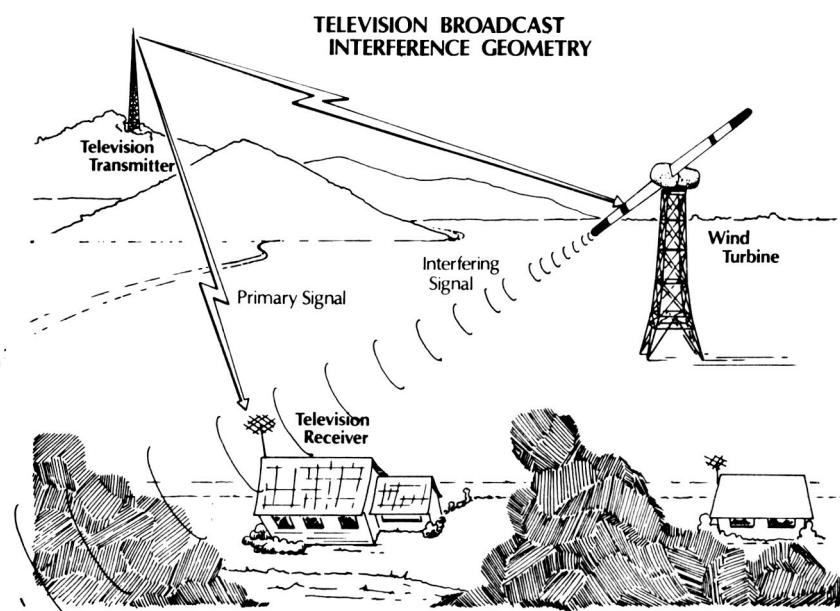


Figure 8

ANNUAL AVERAGE WIND POWER (WATTS/M²) AT 50 M

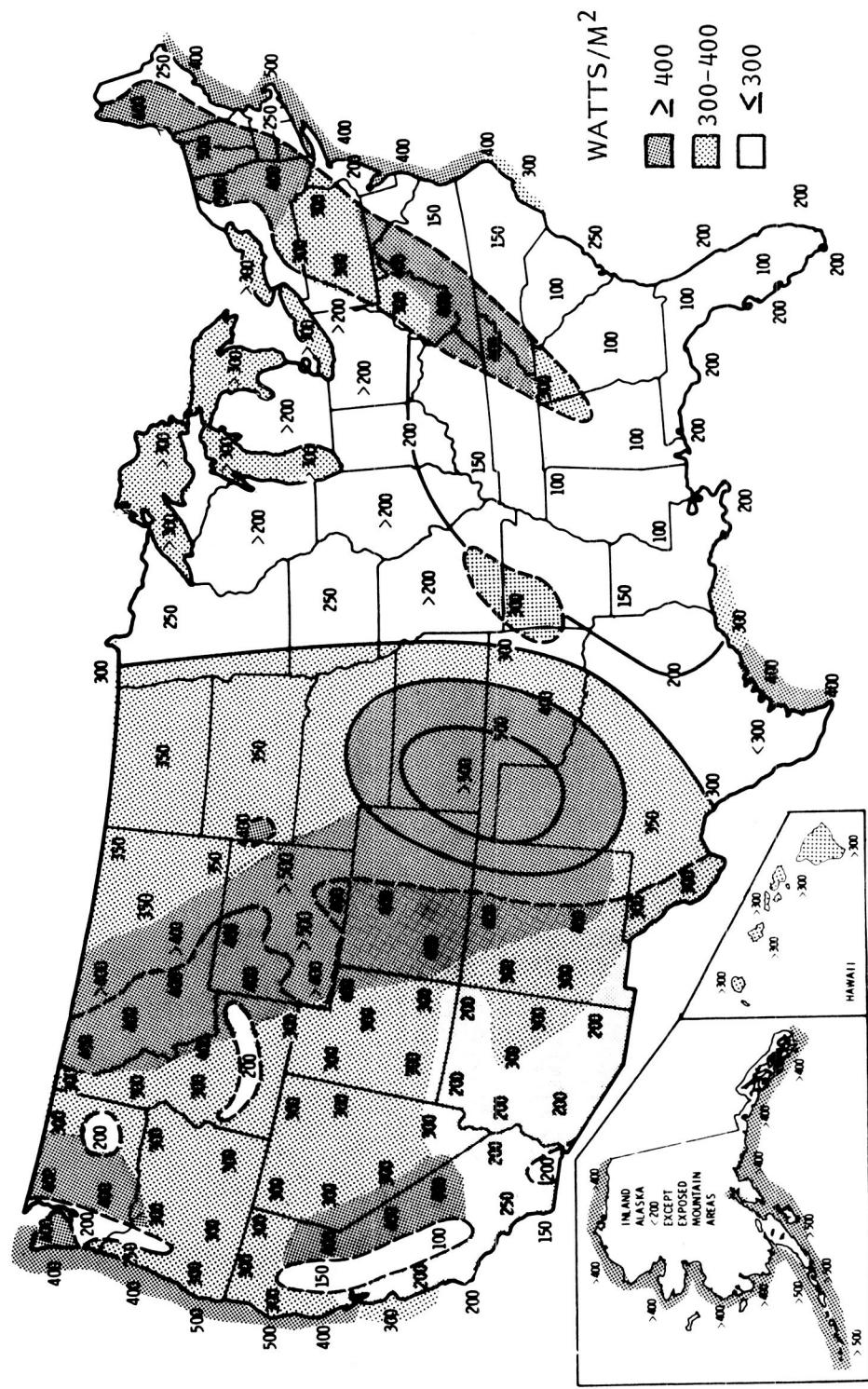


Figure 9

**LOCATIONS FOR WHICH WIND DATA ARE AVAILABLE
IN THE NORTHWESTERN UNITED STATES**

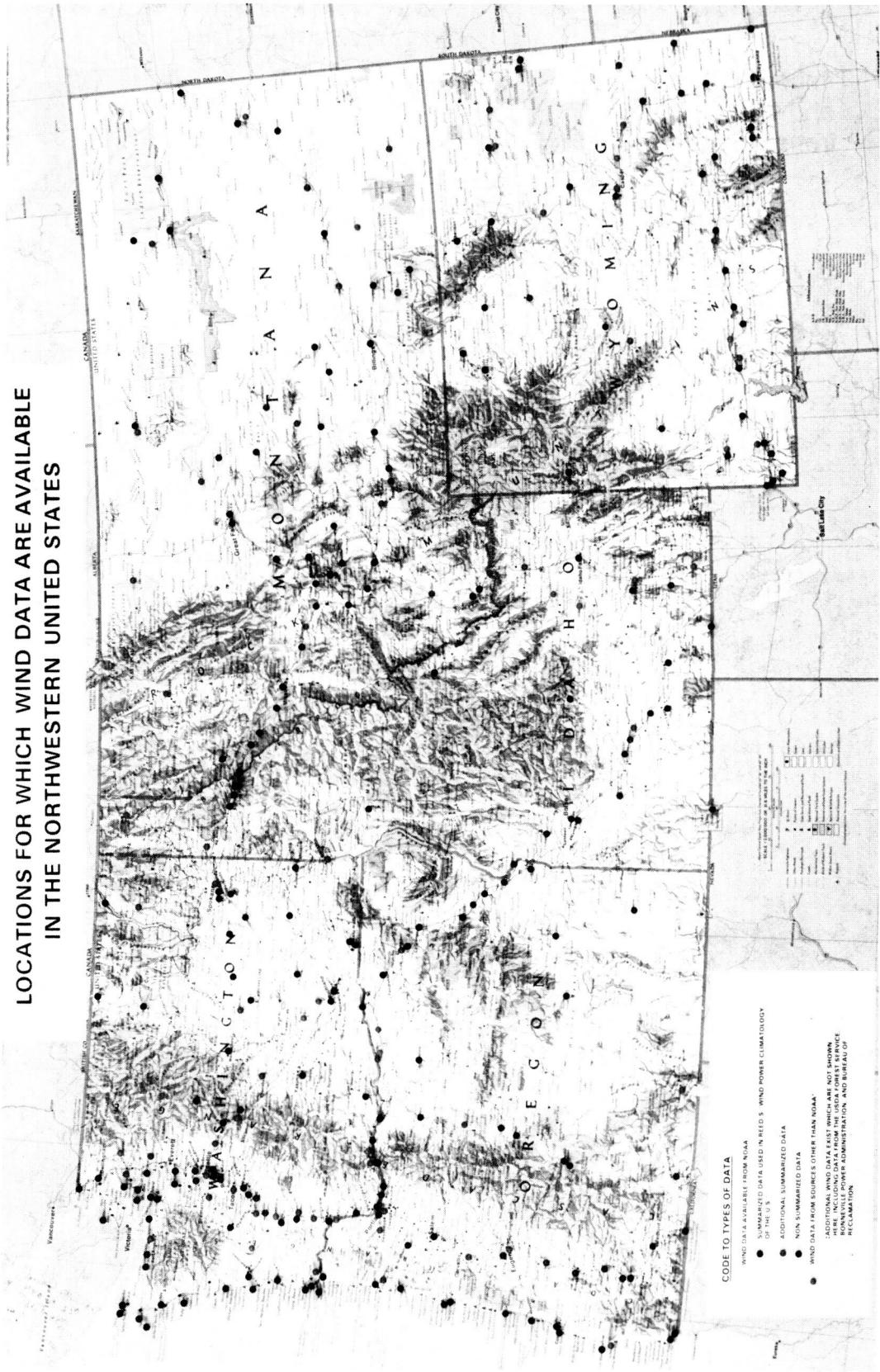


Figure 10

MOD-0 EXPERIMENTAL WIND TURBINE
Plum Brook, Ohio

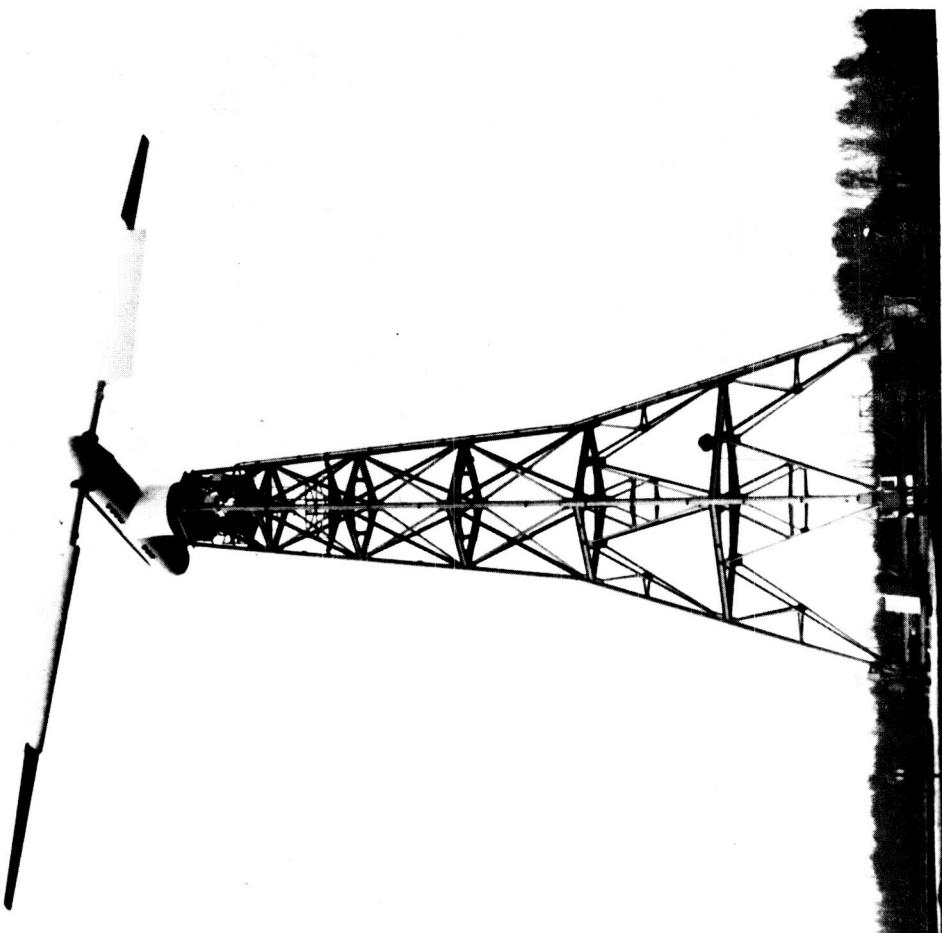


Figure 12

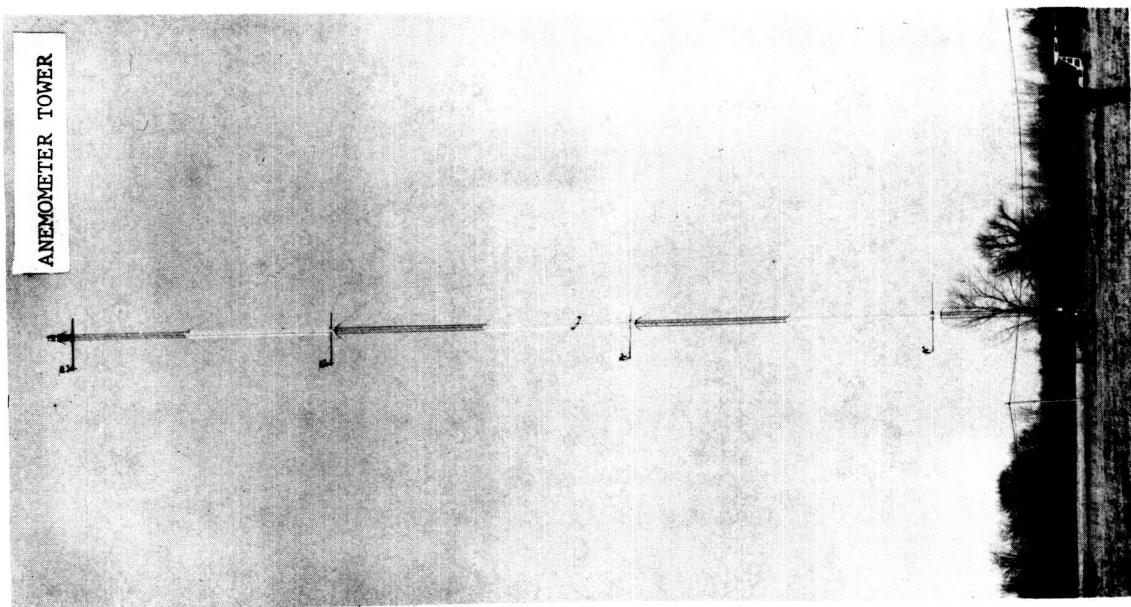


Figure 11

150-FT FIBERGLASS BLADE

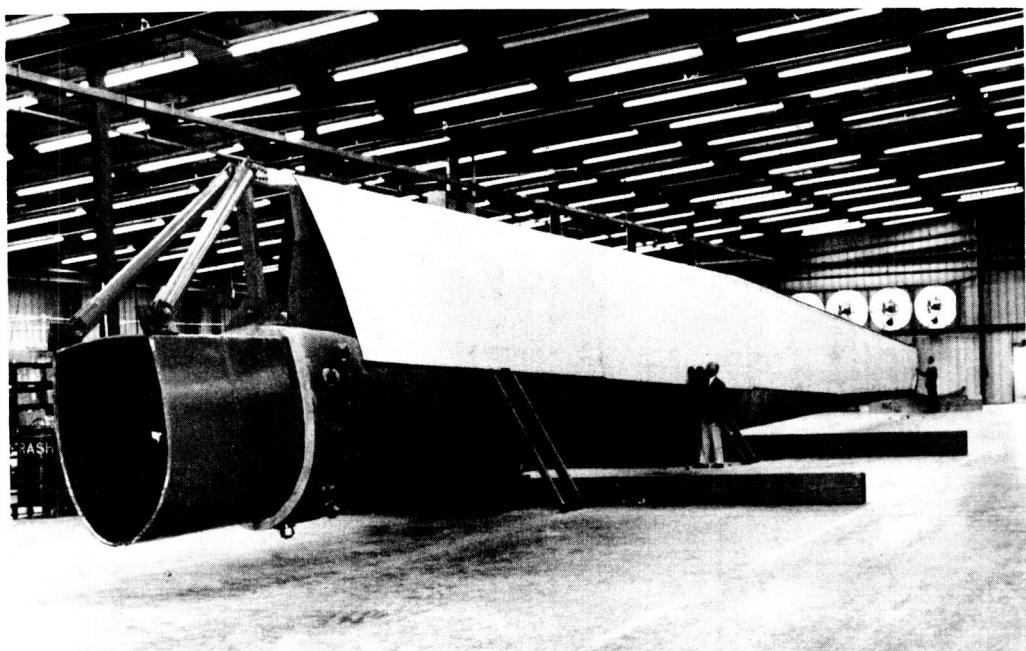
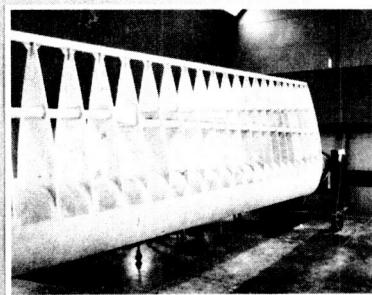
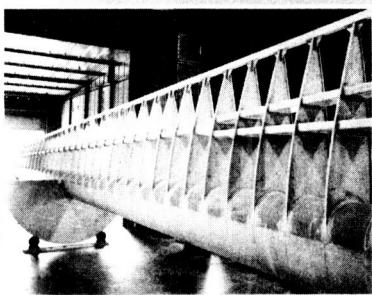


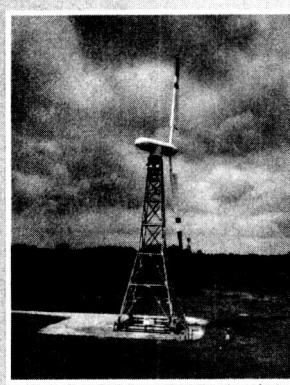
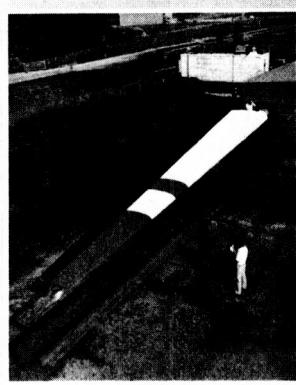
Figure 13

NASA
C-78-4449

UTILITY POLE BLADE



FABRICATION



LOADS APPLICATION

INSTALLATION ON MOD-0

Figure 14

DARRIEUS VERTICAL AXIS WIND TURBINE

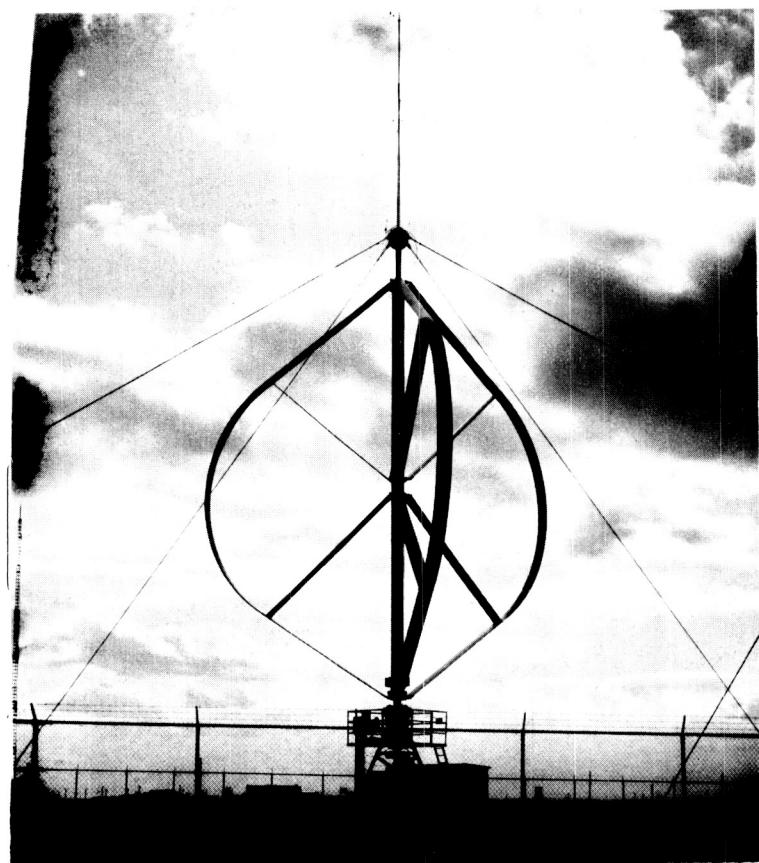


Figure 15

COANDA DIFFUSER CONCEPT

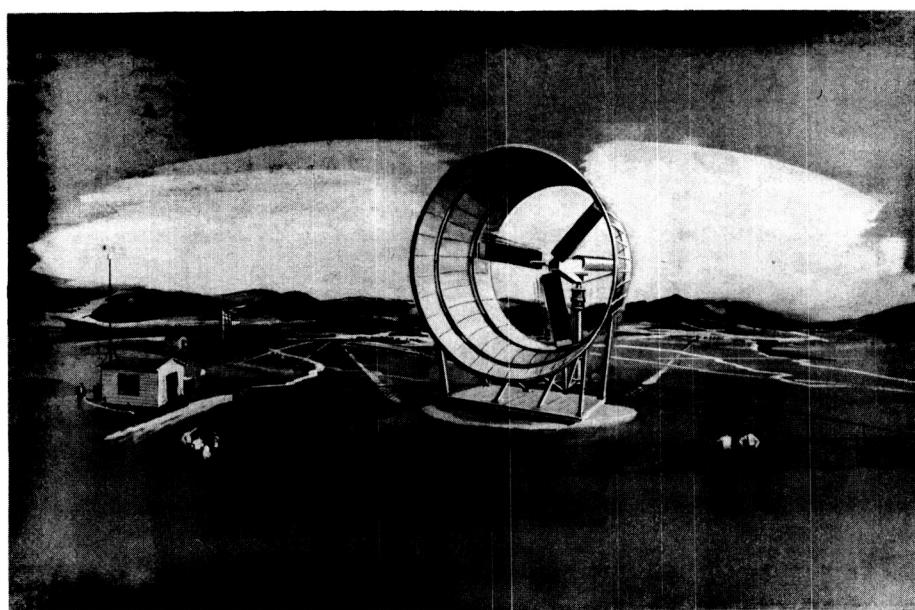


Figure 16

DYNAMIC INDUCER CONCEPT

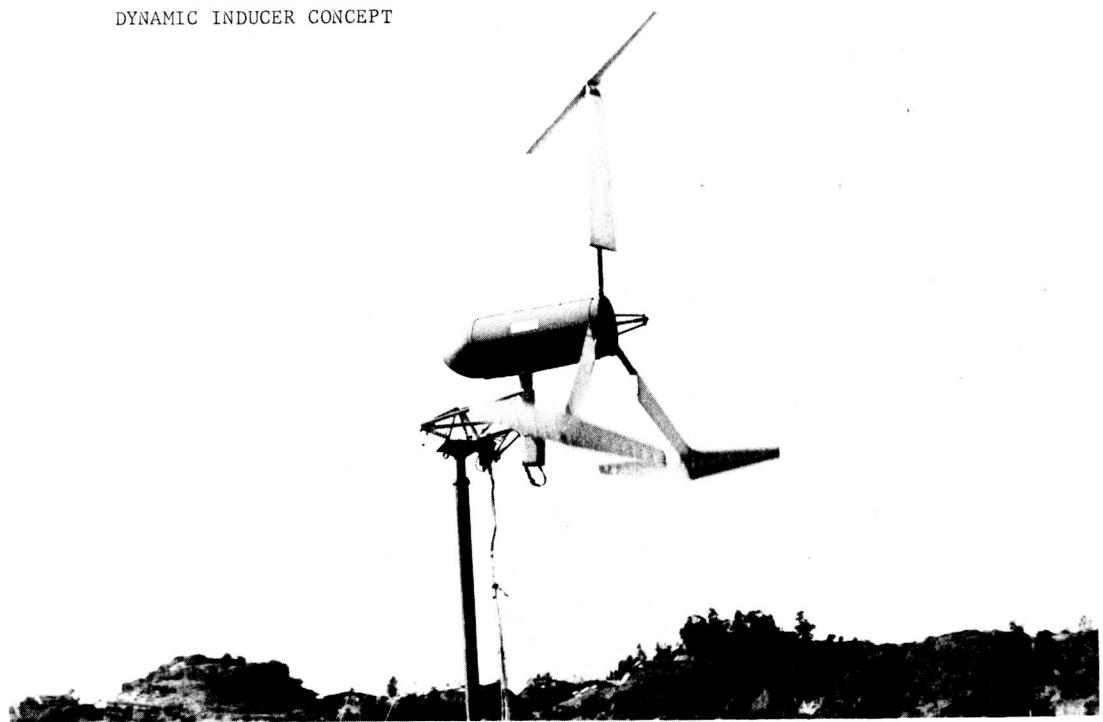


Figure 17

ROCKY FLATS TEST FACILITY

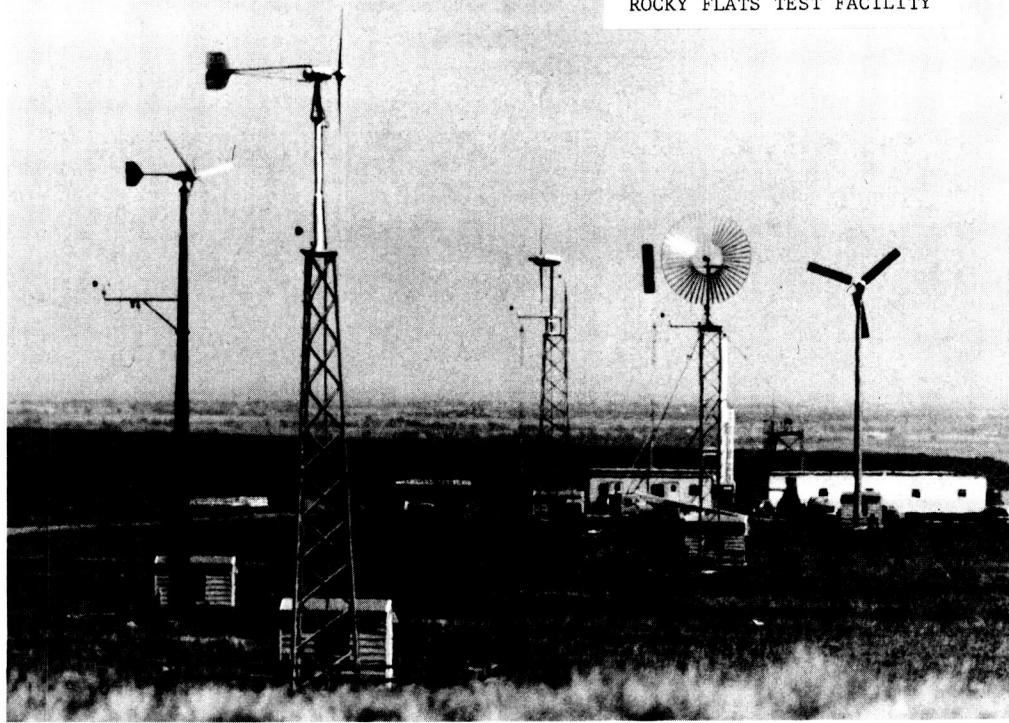


Figure 18

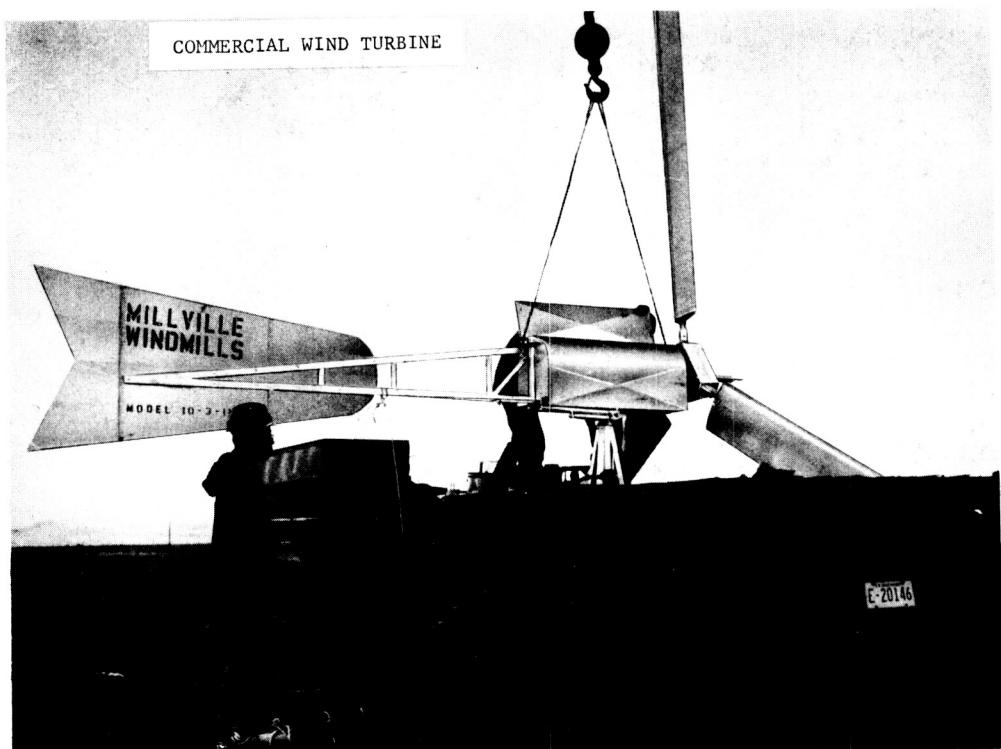


Figure 19

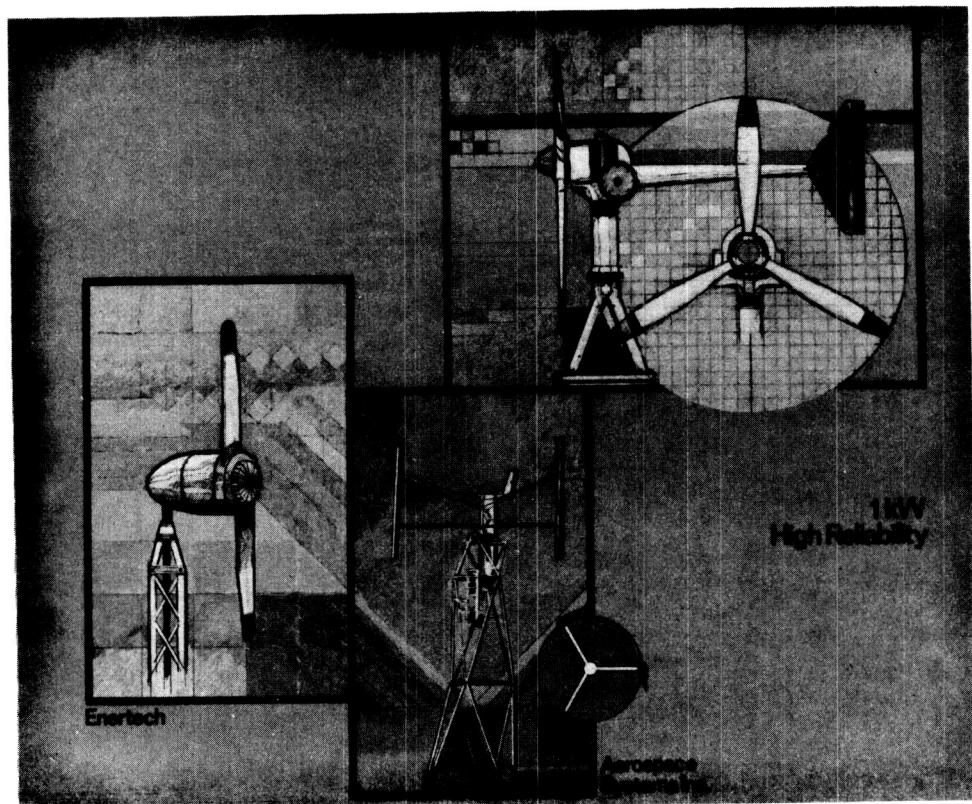


Figure 20

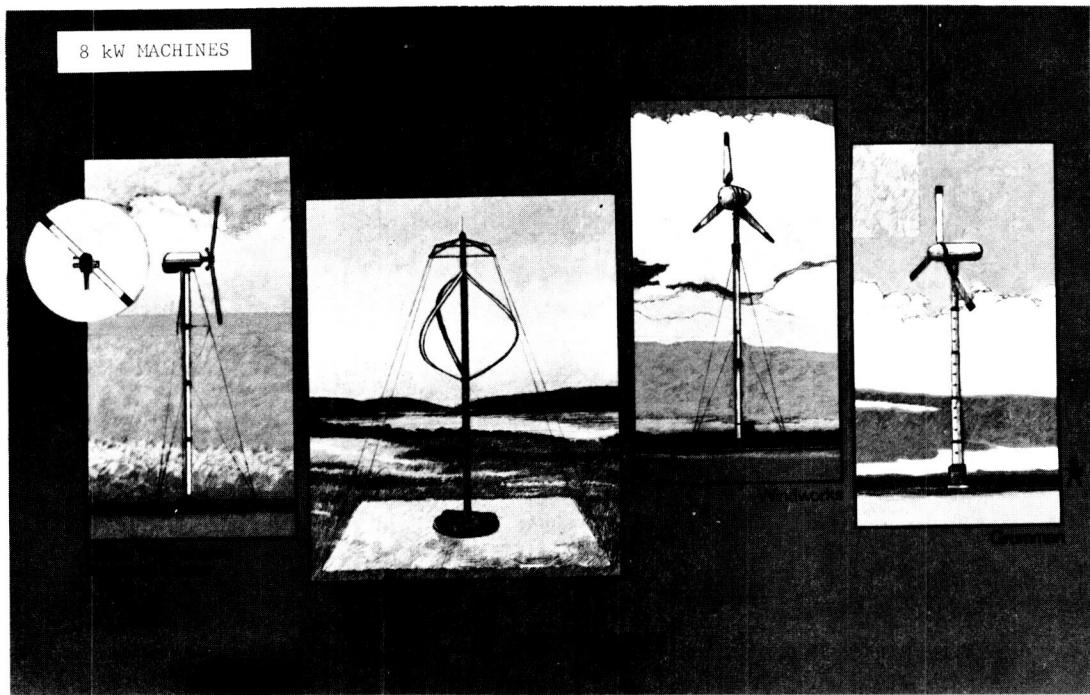


Figure 21

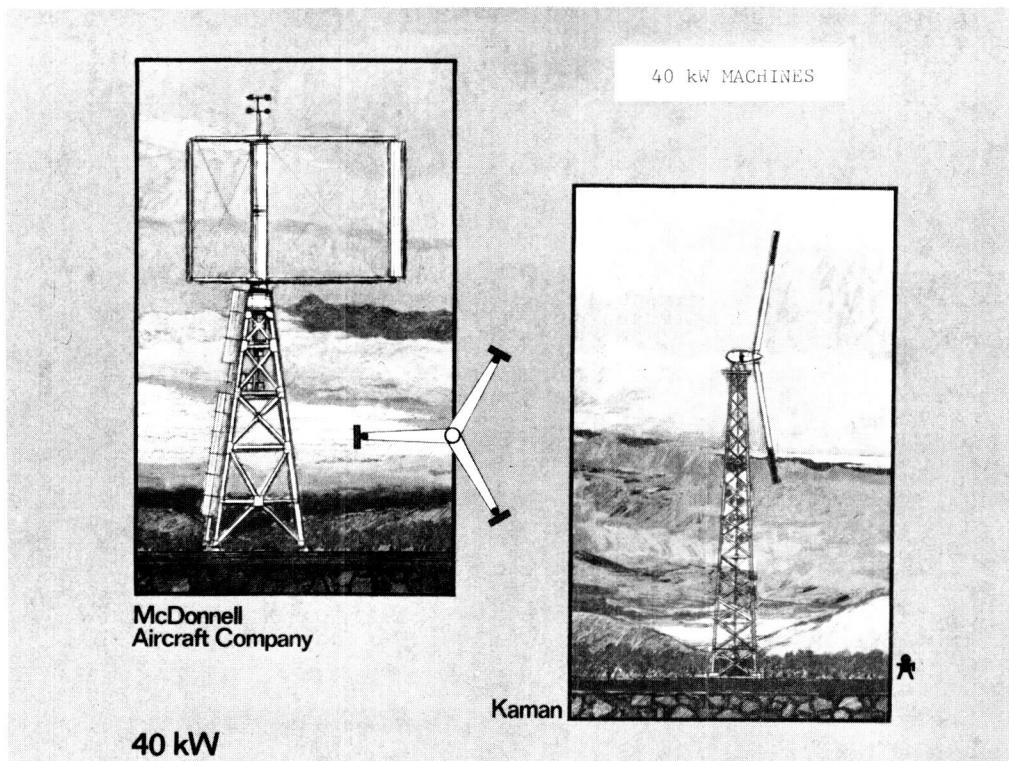


Figure 22

MOD-0A
CLAYTON, NEW MEXICO

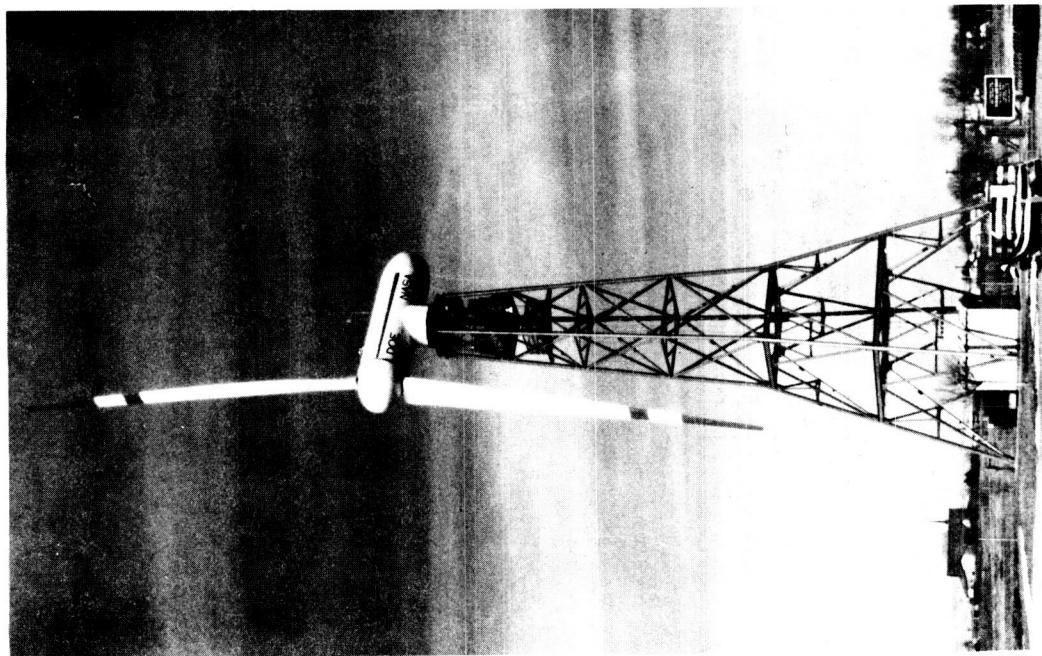


Figure 23

DOE/NASA 2000kW EXPERIMENTAL WIND TURBINE
Howard's Knob, Boone, North Carolina

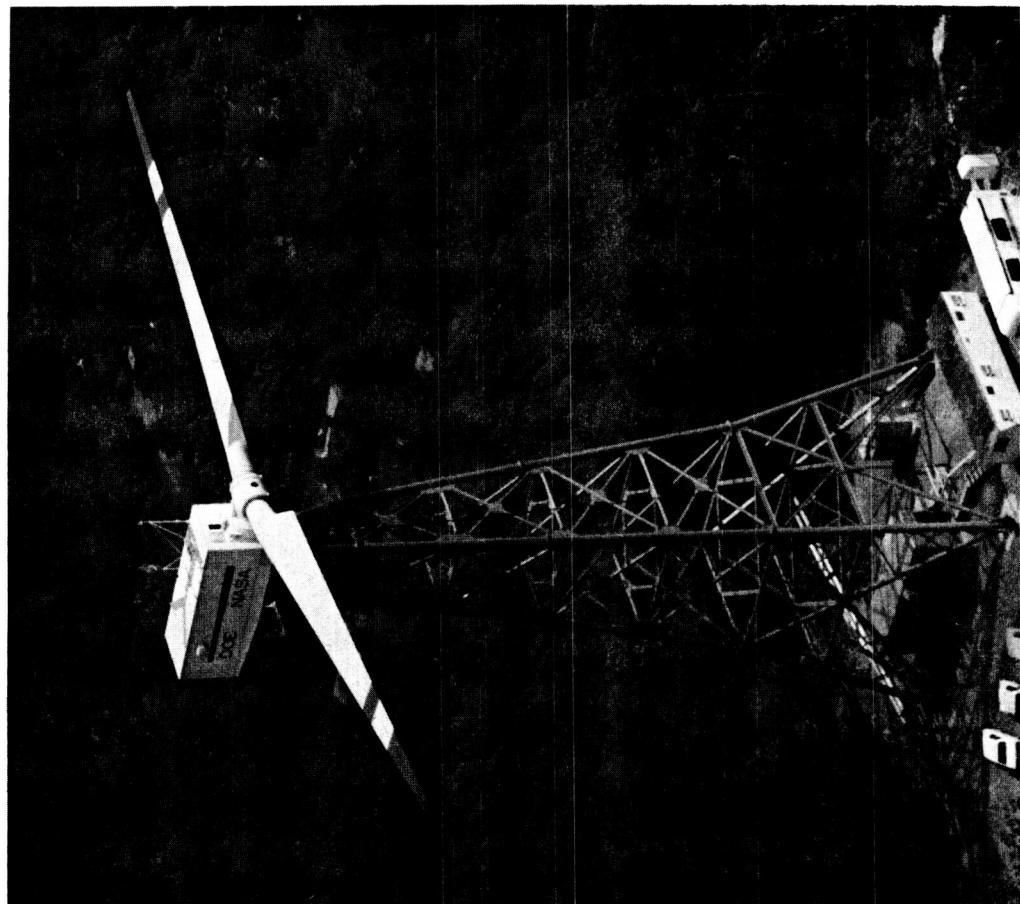


Figure 24

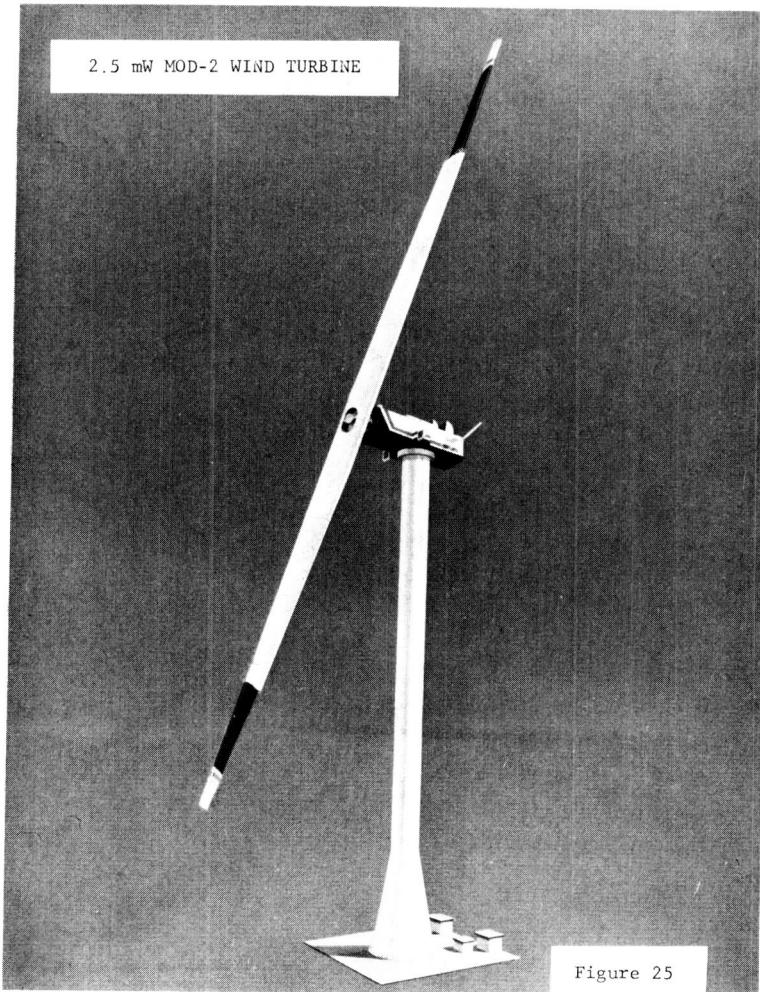


Figure 25

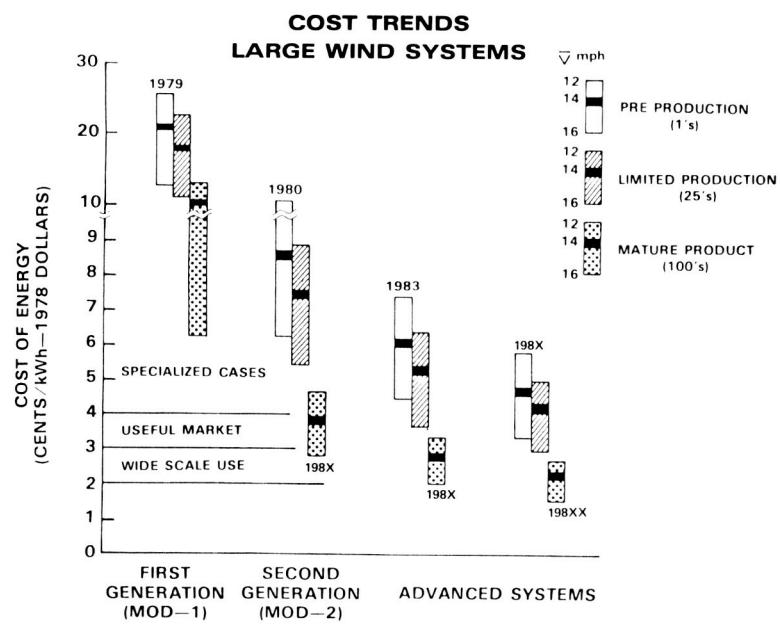


Figure 26

TECHNOLOGY TO REDUCE COE

- MATURE MACHINE COE FROM 3.5¢/kWh TO 2.5¢/kWh
- DETAILED WEIGHT AND COST BUDGETS AND SENSITIVITIES DEVELOPED
- RELATED SUPPORTING TECHNOLOGY PLAN
- TECHNOLOGY AREAS
 - FLAP / SPOILER
 - FIBER GLASS / FABRICATION TECHNIQUES
 - MULTI-SPEED RPM
 - TIPS AND AIRFOILS
 - PASSIVE YAW
 - DAMPING ALLOWING COMPACTION
 - GEARBOX INTEGRATION
 - SELF-ERECTING
 - LOWER LOADS AND FREQUENCIES
 - CONTROL ALGORITHMS
 - SYSTEM CONFIGURATION OPTIMIZATION

Figure 27

Wind Energy Conversion Systems FY 1979 Budget (\$ in Millions)

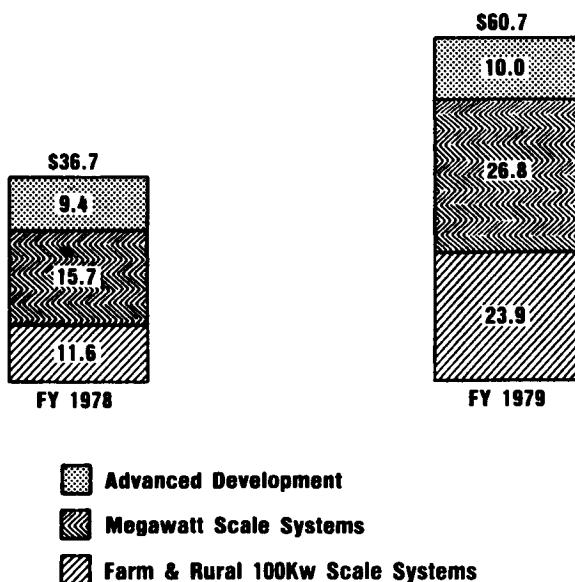


Figure 28